

# VU Research Portal

## Six Reasons Why Supply-oriented Indicators Systematically Overestimate Service Quality in Public Transport

Rietveld, P.

### ***published in***

Transport Reviews  
2005

### ***DOI (link to publisher)***

[10.1080/0144164042000335814](https://doi.org/10.1080/0144164042000335814)

### ***document version***

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

### ***citation for published version (APA)***

Rietveld, P. (2005). Six Reasons Why Supply-oriented Indicators Systematically Overestimate Service Quality in Public Transport. *Transport Reviews*, 25(3), 319-328. <https://doi.org/10.1080/0144164042000335814>

### **General rights**

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

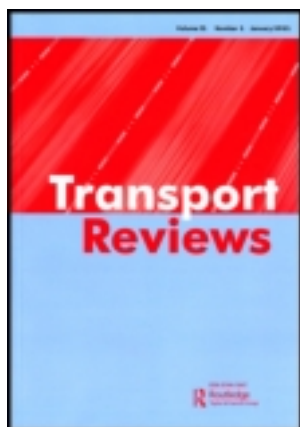
- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

### **Take down policy**

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

### **E-mail address:**

[vuresearchportal.ub@vu.nl](mailto:vuresearchportal.ub@vu.nl)



## Transport Reviews

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/ttrv20>

### Six reasons why supply-oriented indicators systematically overestimate service quality in public transport

PIET RIETVELD

<sup>a</sup> Vrije Universiteit, Amsterdam, the Netherlands

<sup>b</sup> Vrije Universiteit, Boelelaan 1105, 1081 HV Amsterdam, The Netherlands E-mail: [Prietveld@feweb.vu.nl](mailto:Prietveld@feweb.vu.nl)

Available online: 23 Feb 2007

To cite this article: PIET RIETVELD (2005): Six reasons why supply-oriented indicators systematically overestimate service quality in public transport, *Transport Reviews*, 25:3, 319-328

To link to this article: <http://dx.doi.org/10.1080/0144164042000335814>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.tandfonline.com/page/terms-and-conditions>

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan, sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

## Six Reasons Why Supply-oriented Indicators Systematically Overestimate Service Quality in Public Transport

PIET RIETVELD

*Vrije Universiteit, Amsterdam, the Netherlands*

*(Received 1 September 2003; revised 8 June 2004; accepted 6 September 2004)*

**ABSTRACT** *Supply-oriented measures of quality lead to a systematic overestimate of quality as experienced by travellers in public transport. An example is a train with an average occupation rate for seats being 50%, where, nevertheless, the occupation rate observed by travellers is much higher when some parts of the trajectory are busy. Similar examples are discussed for waiting times at stops, probabilities of arriving in time, probabilities of getting a connection and walking distances to bus stops. A plea is then made for putting more effort in measuring demand-oriented quality measures.*

### Introduction

The attractiveness of public transport depends on various factors such as price, travel time and quality. The literature is crowded with studies on the role of price and travel time in travel behaviour (Ben-Akiva and Lerman, 1985; Small, 1992; McCarthy, 2001), but much less is known about the role of quality. In utility-based travel models, the quality aspect is usually addressed by a mode-specific constant, which means that its nature remains implicit. The development of adequate quality measures would be a first step towards a proper treatment of quality in research and policy. The present paper will focus on a bottleneck: quality measurement lagging behind because of data problems. Therefore, quality indicators are often used that have low data requirements, but these indicators tend to be biased. It will be demonstrated that there are various reasons why the quality of public transport as perceived by travellers is systematically different from what the supply-based quality indicators show.

The paper starts with some general reasons why measurements of public transport quality might differ. First, there are pragmatic differences in measurement methods between public transport companies and organizations of travellers. These differences have to do with issues such as exactly where—in which

stations—measurements take place or whether a sample is taken versus all trips considered, etc. In these cases, the background of the differences is rather innocent: the parties in principle measure the same thing, but differences in measurement methods can lead to differences in outcomes. This is not really something to worry about since there are no systematic biases.

Another point of importance concerns the difference between objective measurements and the sentiments of the traveller. An elderly traveller for whom it is important that he/she obtains a seat on a bus or train will put a high priority that there are sufficient seats; even a small probability that no seats are available will be valued negatively. Another aspect is that travellers sometimes make errors in their judgements of probabilities of disturbances. Negative experiences make a bigger impression and tend to be remembered better. In addition, there appears to be a tendency that small errors tend to be overestimated (Tversky and Kahneman, 1992). Thus, when people experience in one per ten times that the bus leaves early from the stop so that they miss their connection, there is a tendency that this probability of buses leaving early is perceived to be higher than 10%. In addition, media attention may lead to an overestimation of disturbances. The media by their very nature focus on events that are different from normal operations according to timetables. For public transport, this means that media attention might lead to overly pessimistic perceptions about the quality of service. This also holds true for road congestion. There is clear evidence that people overestimate probabilities of being affected by congestion problems (Rietveld and Verhoef, 1998).

In addition to these two reasons, there is still a third reason why the two parties might have different images of quality. The problem is that public transport companies may use 'supply'-oriented quality indicators that give results that are different from the quality as perceived by travellers.

The paper will concentrate on these differences between supply- and demand-oriented indicators and formulate the following proposition:

Supply-oriented measures of the quality of public transport services lead systematically to more favourable results than corresponding demand-oriented measures.

This proposition means that supply-oriented measures give an excessively favourable impression of the quality of public transport services. The aim here is to explain the underlying mechanisms of why there are *systematic* differences so that the supplier methodically underestimates the problems perceived by travellers. Since it is the traveller who should be the frame of reference for suppliers, this should induce suppliers to use demand-oriented quality measures. It appears that the degree of sophistication in the use of quality indicators varies considerably between countries. For example, in the Netherlands, public transport companies tend to stick to supply-oriented indicators, whereas in the UK, the use of demand-oriented measures has become common practice in some fields.

Note that it is not claimed that the description of the underlying reasons of systematic differences between supply- and demand-oriented quality measures discussed below is original. They are well known to experts in the field, and they can easily be explained to the layman. The novelty is more in bringing together these various reasons in a unified context.

## Examples of Systematic Differences between Supply and Demand-oriented Measures

### *Waiting Times at Stops*

Consider a bus stop where according to the timetable there should be a bus every 10 minutes at regular intervals. The average waiting time between two successive buses then equals half the inter-arrival time of 5 minutes. Thus, one would be tempted to expect that with a frequency of six buses per hour, the average waiting time of passengers who arrive to the stop without consulting the timetable is 5 minutes. A closer inspection reveals that this only holds when the service is carried out with exact 10-minute inter-arrival times. Consider, for example, the extreme—but not unusual—case that there is no bus for 20 minutes and then suddenly two buses arrive at the same time. The second bus then has no value for the travellers and the average waiting time of those who enter one of these buses is 10 minutes: the second bus has no positive effect on waiting times. Standard theory on waiting times says that when the average inter-arrival time is 10 minutes and the inter-arrival times are exponentially distributed, the expected waiting time of travellers is *twice* the value one could have when the time intervals would be exactly 10 minutes (e.g. Wagner, 1975). The intuition behind this result is that when the time between two consecutive buses increases, the number of passengers confronted with the delay also increases. Conversely, when there are two buses close to each other, there is almost nobody who benefits from this situation. Thus, a long inter-arrival time gets a higher weight than a short one.

It is concluded that the mean inter-arrival time between buses gives an overly favourable impression of the time that travellers have to wait at stops. As soon as there is unreliability, implying a certain variance in inter-arrival times, the mean waiting time is higher than half of the mean inter-arrival time of the buses.

In the Netherlands, this issue of supply versus demand-oriented measures is ignored, whereas in the UK, it is common to take it into account. For example, Wardman *et al.* (2004) indicate that the UK railway industry usually bases its travel demand models on generalized journey time, which depends among other things on service headway. The formulation used takes into account that an equal pattern of departures would reduce service headways (Association of Train Operating Companies, 2002). Along similar lines, formulas have been used for service headways of buses in the UK that take into account the possibility of bunching of vehicle arrivals. The term 'excess waiting time' has been introduced for this purpose to indicate the difference between the waiting time one would have with equally spaced departures and the waiting times actually experienced by travellers (also Hickman, 2001).<sup>1</sup>

The reason why the issue is ignored in the Netherlands probably has to do with the fact that public transport timetables take equally spaced departure times as a starting point, so the problem is limited. However, there are some exceptions to this pattern of equally spaced departure times. For example, on certain railway lines, the inclusion of international trains within the national system leads to unequally spaced departure times. Another example concerns different train, bus or metro lines that share one or more joint links in the network they serve. And, of course, as soon as services based on an equal interval timetable become irregular, the average waiting time at stops will increase.

*Seats in Trains*

Suppose that the seats in a train have a mean occupancy rate of 50%. One would then expect that the mean traveller would be quite satisfied with the supplied capacity. However, the reality for travellers will usually be less attractive, as shown below.

*Trajectory 1 compared with trajectory 2.* Suppose trajectory 1 is very busy and has an occupancy rate of 90%, whereas trajectory 2 has a low occupancy rate of 10%. This indeed leads to a mean occupancy rate of 50%. However, from the perspective of the traveller, the situation is quite different. Suppose for ease of presentation that the travellers alight after trajectory 1, and that the trajectories have equal length. The low occupancy rate of 10% is only observed by 10% of the travellers, and the high occupancy rate by no less than 90% of them. The conclusion is that the average occupancy rate, as perceived by the travellers, equals 82% ( $[0.1 \times 0.1] + [0.9 \times 0.9]$ ). So, high occupancy rates weigh more heavily. This is an explanation of the paradox that buses and trains often have an average occupancy rate during the morning peak that is below 50%, while at the same time there are complaints about crowded vehicles. The high occupancy rates are experienced on the lines to large cities, whereas in the opposite direction, the occupancy rates are low (Rietveld and Roson, 2002).

*Front versus back of a train.* A variant of this problem occurs when occupancy rates in various parts of the train are considered. When a train has an average occupancy rate of 100%, this may look just acceptable because in principle there is a place for everybody. However, suppose that when entering 55% of the passengers enter at the front and 45% at the back. Then the experienced occupancy rate is higher than 100%: ( $[0.55 \times 1.1] + [0.45 \times 0.9]$ ). Finally, 5% of the travellers do not get a seat. The problem of the front versus the back of a train appears to depend on the type of railway station and the location of entrances with respect to the platforms. In particular, terminal stations appear to be vulnerable. Experienced users of the specific rail services will know the best place to enter the trains, which improves the position for travellers with less experience, but not always sufficiently.

*Arriving in Time*

The probability of delays is higher during peak hours. Buses and trains are fuller during these times. In addition, there is a tendency that during peak hours, travellers put a heavier weight on arriving in time at work or an appointment compared with outside the peak. Thus, the average probability of a delay of a bus or train indicates little of the number of passengers who are affected and the size of the effect. Suppose, for example, that 80% of the trains arrive in time and 20% are late. Suppose too that the number of users of the late trains is twice as large as in the trains that are on time. The reason is that during the peak, occupancy rates are higher, and besides trains are often longer during peak hours. Thus, from the perspective of the traveller, the share of the late arrivals is not 20%, but  $\{(2 \times 20) / (80 + [2 \times 20])\} = 33\%$ .

The extent to which operators are stimulated to take into account the number of passengers in these measures varies. For example, in the Netherlands, the

contract between the Ministry of Transport and the Netherlands Railways contains a standard on the number of trains being in time (with a 3-minute tolerance standard). Thus, the issue of the number of passengers affected is not covered here. In the UK, a public performance measure has been introduced in a similar way, in this case with a 5-minute tolerance standard (Department for Transport, 2002). Therefore, here too the standard is in terms of the number of trains, not in terms of passengers.<sup>2</sup> However, the demand element is included to some extent in the incentive structure since train-operating companies that are under-performing in this respect are confronted with fines that depend on the time of day (peak versus off-peak).

Another aspect is that there may also be direct compensation to passengers given by train operators when the delay is longer than a certain standard. In the UK, travellers who experience delays longer than 60 minutes obtain a refund of 20% of the ticket price. In Germany, a similar measure has been proposed. In the Netherlands, the standard is stricter: after delays of more than 30 minutes, the passenger can claim compensation up to the full ticket price.<sup>3</sup> These approaches, which have become common in Europe, imply that the railway company has a direct interest to know how many passengers will be affected when trains are delayed. This would provide clear incentives to develop a system of traveller-oriented performance measures. Data problems might be an explanation why developments of dedicated measures into this direction have been slow.<sup>4</sup>

#### *Probability of Missing a Connection*

The probability of disturbances is larger in the peak than in the off-peak times. Further, buses and trains are fuller in the peak than off-peak. The result is that—precisely as above—the share of the travellers who miss their connection is larger than the percentage of trains that according to the timetable would have to give a connection.

#### *Propagation of Delays in Multimodal Chains*

Public transport passengers usually make trips where various modes are employed. For the passenger it is the quality of the entire chain that matters, not that of the individual elements of the chain. Supply-oriented indicators of service quality focus on the performance of one operator, whereas travellers usually face more than one operator. In many cases, the traveller him/herself takes care of access or egress, e.g. when they walk, cycle or use a car. In such cases, the multimodality usually does not aggravate quality problems. When the last part of the trip from the railway station to the final destination takes place by walking, the multimodality features do not lead to specific insights for the current discussion. Only in rather exceptional cases, multimodality might aggravate the effects of the delay. An example is that late train arrival may mean that the guarded bicycle shed at the station is already closed. Another example is that the delayed train leads to a pedestrian walking in the dark, so that people may feel unsafe.

In the case that access and egress are taken care of by other transport modes, quality problems of a more general nature may occur, because when a train arrives 5 minutes late, the traveller might miss the connecting bus, possibly leading to a much longer delay. This problem will be investigated here in more detail. A supplier-oriented quality measure would ignore the complexities for travellers



who have to change from one operator to another, or from one mode to another. It is not necessarily so that travellers are always negatively affected in this context. A late arrival of the train may simply mean that the waiting time for the bus is shorter, so that the net effect on total travel time is zero. But when the connection is missed, there will be a large penalty. To see whether there is any systematic element in the effect of multimodality on late arrivals, one can compare the case where the egress mode is of a very high frequency. In that case, multimodality does not really matter: a metro leaving every 5 minutes from the railway station does not have a systematic aggravating effect on the total travel once the delay of the train is known.

However, in the case of a lowly frequent bus service bringing the passenger from the railway station to their final destination, the situation differs. Consider, for example, a train with a frequency of twice per hour and a connecting bus leaving once per hour. In this case, the traveller will choose the train that arrives closest to the departure time of the bus. When timetables of bus and train are not coordinated, this would imply a transfer time that is at most 30 minutes, the expected time being 15 minutes. Suppose for ease of calculation that the train's delay is uniformly distributed between 0 and 60 minutes, which implies an average delay of 30 minutes. In that case, there is a probability of 0.25 that the delay of the train is entirely absorbed by the waiting time for the bus, so that the traveller would be better off than the train statistics would suggest. On the other hand, there is a probability of 0.75 that the traveller is worse off because the delay of 15 minutes for the train becomes 60 minutes for the total trip. Thus, under these assumptions, the expected delay for the traveller's total trip becomes 45 minutes instead of the 30 minutes for the rail portion. Note that the result depends essentially on the frequencies of the modes. When the frequency of the bus and train are equal (or when the bus frequency is higher), the aggravation effect vanishes.

In addition, the assumption of a lack of timetable coordination has to be considered. Consider, for example, the case that the timetables of bus and train are coordinated. One can then assume that the bus will leave rather soon after the scheduled arrival of the train, say 5 minutes later. In this case, a uniform distribution of the delay of the train between 0 and 60 minutes would mean that the actual delay is zero minutes with a probability  $5/60$  and 60 minutes with probability  $55/60$ . Therefore, in the case of the coordination of timetables, the aggravating effect of delays is even worse: it increases from 30 to 55 minutes.<sup>5</sup>

In conclusion, problems of delays in a certain mode may lead to aggravation of the delay when another mode has to be used to bring the traveller to his/her final destination. The aggravation is substantial when one of the two following conditions apply: the final mode has a low frequency, and timetables of the two modes have been coordinated.

### *Walking Distance to the Bus Stop*

The last example in this list of items is of a somewhat different nature. It extends the discussion from temporal aspects to spatial ones, while still using the same type of reasoning by comparing the supplier's perspective (spatial distance between stops) and the traveller's perspective (distance to be walked from their residence to a stop). Consider stop distances in public transport (e.g. 400 metres between bus stops). Then the maximum walking distance between two stops is 200 metres, and when passengers are distributed equally along the line, the average walking



distance is 100 metres. First, note that the issue of stop distances and walking distances is the spatial equivalent of the issue of inter-arrival times and walking distances. Thus, the result obtained above, that mean inter-arrival time leads to underestimates of waiting times, also applies in this context. Consider, for example, three stops with distances 200 and 600 metres. The mean distance between stops is then 400 metres. However, when travellers are uniformly distributed between stops, the average walking distance is  $([0.25 \times 50] + [0.75 \times 150]) = 125$  instead of 100 metres,<sup>6</sup> which is consistent with the above results.

However, there is another point to be made because there is a principal difference between space and time: time is one-dimensional whereas space is two-dimensional. The above calculations only make sense when a population lives along a line. But how are the results affected when residential land use is accounted for in two-dimensional space. Consider, for example, the case of circular residential structures where along each stop, a circle filled with residences has been built. Figure 1 shows two stops A and B. Let the distance between the stops be  $2r$ , and the radius of the circle be  $r$ , so that the various circles are just tangents to each other. The average distance of points in a circle with a radius  $r$  to the centre can be shown to be  $(2/3)r$ . One might think that it equals  $(1/2)r$ , which would be the average walking distance of all people living along a radius to the centre. The background of this result is that the outer end of the radius has a higher weight because there is more space for dwellings than when close to the centre.<sup>7</sup> The conclusion is that average stop distance underestimates the walking distance for residents to stops. To arrive at more precise measures, one would need data from planners on actual settlement patterns. For practical purposes, geographical information systems would be very helpful to compute the relevant distance. Another possibility would be to use data on access times as reported by travellers in national travel surveys, although these would probably only give an average and not a specific figure for individual lines due to insufficient coverage. Note that this entails the adoption of a user-oriented approach, because the focus is no longer on the distance of the stops offered by the supplier, but on the distances walked by the travellers.

## Discussion

In public transport, there are various reasons why disturbances (delays, reduced availability of seats, etc.) are more serious for travellers than might be inferred from supply-oriented indicators. A summary is given in Table 1.

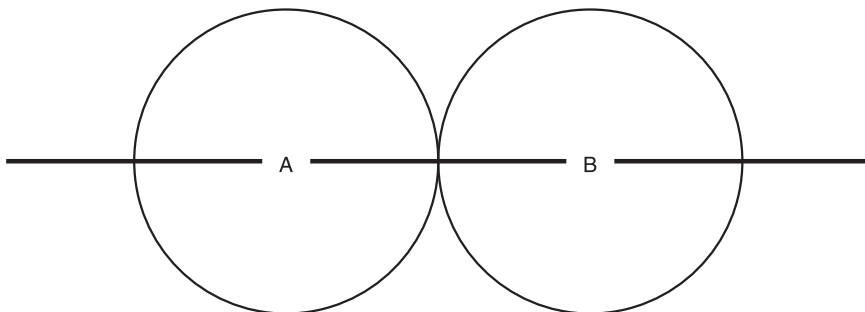


Figure 1. Location of stops along public transport line with circular settlements

**Table 1.** Comparison of supply- and demand-oriented quality measures in public transport

	Supply oriented	Demand oriented
1	Mean inter-arrival time of buses, frequency	Mean waiting time of traveller
2a	Mean occupancy rate of seats	Mean experienced occupancy rate by traveller
2b	Mean occupancy rate of seats	Percentage of travellers that could not find a seat
3	Share of trains/seats that arrives in time	Share of travellers who arrive in time
4	Probability that a bus/train misses a connection	Probability that travellers miss a connection
5	Late arrival of trains in stations	Late arrival of traveller at their final destination
6	Distance between stops	Average walking distance of travellers from their home to a stop

The main reason for the systematic underestimate of quality problems as experienced by travellers when supply-oriented measures are used is that situations of bad quality tend to coincide with busy periods whereas good quality tends to coincide with quiet periods.

The discussion above emphasized the differences between the demand- and supply-oriented quality measures. Nevertheless, the two types of measures are obviously related: improving transport system performance according to a supply-oriented measure will usually also lead to a better score for the demand-oriented measure. Therefore, one may wonder what is the damage when firms would stick to supply-oriented measures, all the more since the information systems of public transport companies are often not good enough to measure quality from the demand side.

The answer is that it remains important that suppliers try to measure the quality as perceived by customers. First, this is the best way to make the management and employees in the transport companies aware of quality problems as perceived by customers. It helps prevent the situation that firms are satisfied but travellers are not.

In this context, note that in many countries public transport companies carry out surveys on traveller satisfaction where respondents are asked to give their opinion on many quality aspects, e.g. by giving school report marks.<sup>8</sup> Especially when such attitudinal data are collected regularly and systematically, this is a praiseworthy activity that might yield many useful insights. However, it does not entirely solve the problem. For example, after disappointing experiences, travellers may apply downward adjustment of their aspirations so that the scores of satisfaction surveys may give a rosy view. Another problem is that travellers may drop out as customers of public transport because they are not satisfied at all, which means their views are not represented in the survey.

Transport companies that ignore demand-oriented quality measures have to face the problems following from this situation. This holds true, for example, for train-operating companies that give compensation to passengers who experience

delays above a certain threshold. When these companies do not develop information systems on delays based on the number of passengers affected, they run the risk of unnecessary large amounts of compensation. And, since low service quality leads to a loss of customers, appropriate quality indicators should be included in transport demand models. The use of the excess travel time indicator in the UK demonstrates that this is well within reach. But there is still substantial scope for wider application of demand-oriented measures in the UK and more so in many other countries.

An important feature of quality measures is that they tend to bring incentives with them. When supply-oriented criteria are used, there is a risk that efforts are focused on matters that are not the most effective way to make travellers experience better quality. In theory, it might even happen that measures to improve performance according to the supply perspective might have adverse effects on demand-oriented criteria. An example is what happened in the Netherlands where the punctuality of trains became the dominant evaluation criterion imposed by the government. Consequently, the railway company changed its routine that trains could wait a few additional minutes at a hub station in order to allow passengers from a slightly delayed train to catch their connection in order to reduce the risk that more trains would be delayed. However, the final effect for passengers might well be negative since it means that more travellers will miss a connecting train.

The problem that the present information systems are insufficient to measure demand-oriented criteria should be taken seriously. The main point is that public transport companies usually do not measure directly how many travellers there are in their vehicles. Such a measurement may indeed be very costly. Therefore, transport companies often use model-based approaches to estimate the actual number of travellers entering and alighting their vehicles at all stops. The quality of such models varies. One might wonder why governments in many countries are not keener in using demand-oriented quality measures in contracts with licensees. A possible explanation is that governments are reluctant because of measurement problems. Data on delayed trains might be easy to measure based on an independent actor such as rail traffic control. For demand-oriented measures, these data have to be complemented with data on the numbers of travellers per train. When these are to be generated by means of models developed by the transport companies, there is a risk of lengthy discussions on the validity of the model approaches. Governments might wish to avoid such difficulties by sticking to supply-oriented measures.

It is possible that future technological developments will have a major impact on this issue of quality indicators. Many countries are considering the introduction of chip cards in public transport in some form, and these will be a major step forward in the collection of data on passenger movements. But public transport companies do not have to wait for this to occur. There must also be other routes that enable them to mobilize information so that better quality measures are within reach.

### **Acknowledgements**

The author thanks Johan van Dalen, Mark van Hagen, Niek van Trigt and Bert van Wee for constructive comments. Also gratefully acknowledged are two anonymous referees for helpful comments.

## Notes

1. A typical example of the ways in which the excess waiting time is incorporated in quality reports is provided by Transport for London. For each route, the scheduled waiting time is given, based on timetables, complemented by excess waiting due to departures from the timetables. For buses, one gets values for scheduled waiting times ranging from 4.0 to 6.0 minutes, with corresponding excess waiting time values from 0.6 to 1.5 minutes. Note that there is a difference in the way bus and train are treated. For buses, excess waiting time incorporates both variations in scheduled headway (e.g. when several routes converge, even if each runs its own regular headway pattern) and day-to-day variations in running. For rail, the variations in service headways, as they are used in modelling work, tend to be based on scheduled service patterns. For the benchmarking of railway companies, the variations, however, are based on actual realisations of the timetable (see also the section 'Arriving in Time').
2. The public performance measure is used among other measures for benchmarking purposes by comparing the various railway operators in the UK.
3. There are some limitations: below certain minimum fare levels (related to reduced fares and/or short distances), travellers will not get compensation.
4. A related reason might be that direct measurement of passenger flows is expensive, so that in many cases, model-based estimations have to be made about how many travellers would be in a specific train.
5. It might sound implausible that timetable coordination has an adverse effect on expected delay in this multimodal trip. The positive effect of the coordination is, of course, that the waiting time at the station in the case of certain arrivals and departures becomes lower. In the present example, it decreases from an expected 15 minutes to 5 minutes. Of course, when not only the timetables are coordinated, but also the actual operations, the adverse effect on delays may be mitigated: when the bus waits for the delayed train, the adverse effect on reliability will disappear. However, slack in timetables, in general, will not allow much flexibility in this respect.
6. A necessary nuance is that in space, travellers may not be uniformly distributed, so that in certain cases, irregular stop distances might have a favourable effect on walking distances to the stops.
7. Or put differently, the average distance of points in the circle with radius  $r$  to the centre is the weighted mean of the distances between 0 and  $r$ , where the weight is proportional to  $r$  since the length of a circle is proportional to  $r$ . Note that uniform density is assumed.
8. In some countries, such quality measurements by passengers are part of the contract between government and the transport company that obtained the license.

## References

- Association of Train Operating Companies (2002) *Passenger Demand Forecasting Handbook* (London: ATOC).
- Ben-Akiva, M. and Lerman, S. (1985) *Discrete Choice Analysis* (Cambridge, MA: MIT Press).
- Department for Transport (2002) *Transport Ten Year Plan 2000: Delivering Better Transport—Progress Report* (London: DoT).
- Hickman, M. D. (2001) An analytic stochastic model for the transit vehicle holding problem, *Transportation Science*, 35, pp. 215–237.
- McCarthy, P. (2001) *Transportation Economics* (Oxford: Blackwell).
- Rietveld, P. and Roson, R. (2002) Direction dependent prices in public transport: a good idea? The back haul pricing problem for a monopolistic public transport firm, *Transportation*, 29, pp. 397–417.
- Rietveld, P. and Verhoef, E. T. (1998) Social feasibility of policies to reduce externalities, in: K. J. Button and E. T. Verhoef (Eds) *Road Pricing, Traffic Congestion and the Environment*, pp. 285–307 (Cheltenham: Edward Elgar).
- Small, K. (1992) *Urban Transportation Economics* (London: Harwood).
- Tversky, A. and Kahneman, D. (1992) Advances in prospect theory, *Journal of Risk and Uncertainty*, 5, pp. 297–323.
- Wagner, H. (1975) *Principles of Operations Research* (Englewood Cliffs: Prentice-Hall).
- Wardman, M., Nash, C., Shires, J., Johnson, D., Lythgoe, B. and Tyler, J. (2004) Appraising the benefits of regular train timetables. Paper presented at WCTR, Istanbul, Turkey, 2004.